

Kinematic Analysis Using Profile and Time-Slice Animations of 3-D Seismic Volumes: Examples from the Rocky Mountain Foreland Province*

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Abstract

Kinematic analysis of geologic structures capable of entrapping hydrocarbons has traditionally been constrained by an incomplete subsurface database. Now that high-quality 3D data volumes have become available for study and interpretation, complete images of the geometry of subsurface structures are available. By creating animations with continuous profiling moving through a 3D data volume in a selected direction, a vivid mental image of the structure is created. For example, in the case of ubiquitous basement-involved thrust-generated folds of the foreland province, a profile movie using profiles oriented orthogonally to the strike of the causal thrust and advancing from the tip of the thrust to the area of maximum displacement and maximum fold amplitude, a self-same image of the kinematic development of the structure is created. Also, time-slice animation of 3D volumes can contribute to better interpretations of the kinematic development of subsurface geologic structures. For example, bottom-up movies can—with the appearance of fault-plane reflections within basement—expose the nucleation and upward propagation of fold-generating thrust zones, and top-down movies can bring to light the evolution of circular rim structures and the downward narrowing of rootless impact structures.

Movies of three structural oil fields in the Rocky Mountain foreland province are presented and discussed: 1) the giant Salt Creek anticlinal oil field on the Casper Arch, a Laramide basement-involved thrust-generated fold, 2) the nearby Sussex oil field, a fault-parallel, basculating,

pop-up structure at the Paleozoic level produced by left-lateral shearing along a reactivated wrench zone, and 3) the Red Wing Creek field in the Williston Basin; a 9-km-diameter, impact structure buried beneath Jurassic strata and supporting a 2800-foot oil column within the Mississippian chaos of the central peak.

Cited References

Beck, E., 1929, Salt Creek oil field, Natrona County, Wyoming: AAPG, Structure of Typical American Oil Fields, v. 2, p. 589-603.

Padden, M., 1958, Sussex-Meadow Creek area, *in* Powder River Basin of Wyoming: 13th Annual Field Conference Guidebook, p. 196-199.

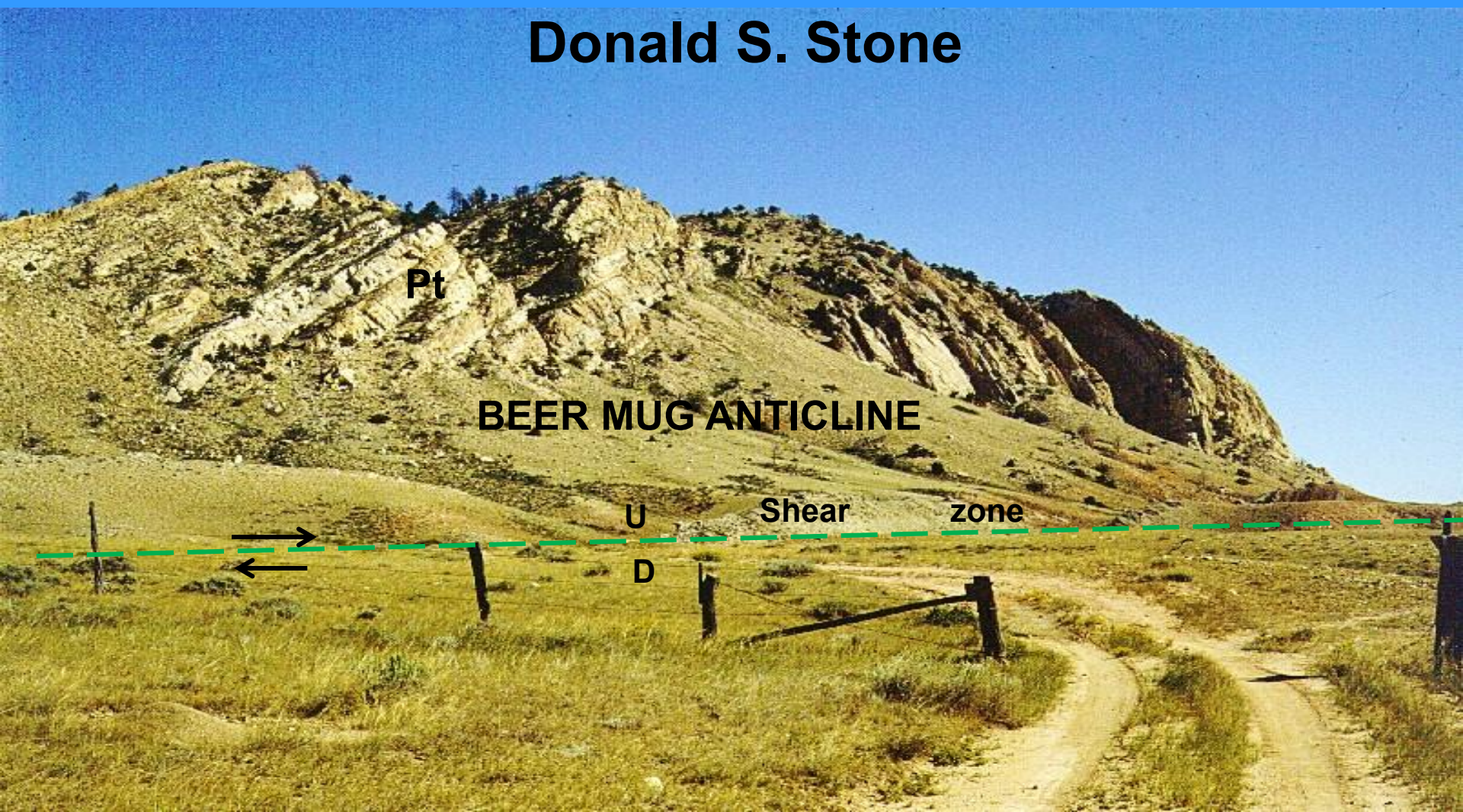
Stone, D.S., 1995, Structure and kinematic genesis of the Quealy wrench duplex transpressional reactivation of the Precambrian Cheyenne belt in the Laramie basin, Wyoming: AAPG Bulletin, v. 79, p. 1349-1376.

Stone, D.S., 2005, On illogical interpretation of geological structures in the Rocky Mountain foreland province: *The Mountain Geologist*, v. 42/4, p. 159-185.



KINEMATIC ANALYSIS USING PROFILE AND TIME-SLICE ANIMATIONS OF 3D SEISMIC VOLUMES; EXAMPLES FROM THE ROCKY MOUNTAIN FORELAND PROVINCE

Donald S. Stone





DEFINITIONS

- **KINEMATIC ANALYSIS**

- Involves the interpretation of combinations of translations, rotations, dilations, and distortions that altered the location and orientation, size, and shape of a body of rock, including rigid-body and non-rigid-body movements.

- **SELF-SAME IMAGING**

- The concept that the kinematic development that occurred in place at the center of a geologic structure can be simulated by animating sequential dip profiles through the structure from its tip or edge to the area of greatest development (e.g., fault slip and/or fold amplitude) at the center of the structure.



Purpose

----- is to show that seismic-profile and time-slice animations made from 3D seismic data volumes provide a unique source of visual data for kinematic analysis of subsurface structures based on the concept of *self-same imaging*. This is illustrated by the data from three important oil field structures in the Rocky Mountain foreland.

Oil Field

1. Salt Creek

Structural Class

basement-involved
thrust-generated fold(BITGF)

2. Sussex

basculating, left-lateral
wrench fault zone

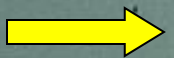
3. Red Wing Creek

complex impact structure



ANALOGUE CLAY MODEL STUDY (1985) OF A BASEMENT-INVOLVED THRUST-GENERATED FOLD

AFTER 18% SHORTENING



SALT, CORNSTARCH, WATER

(Mz)

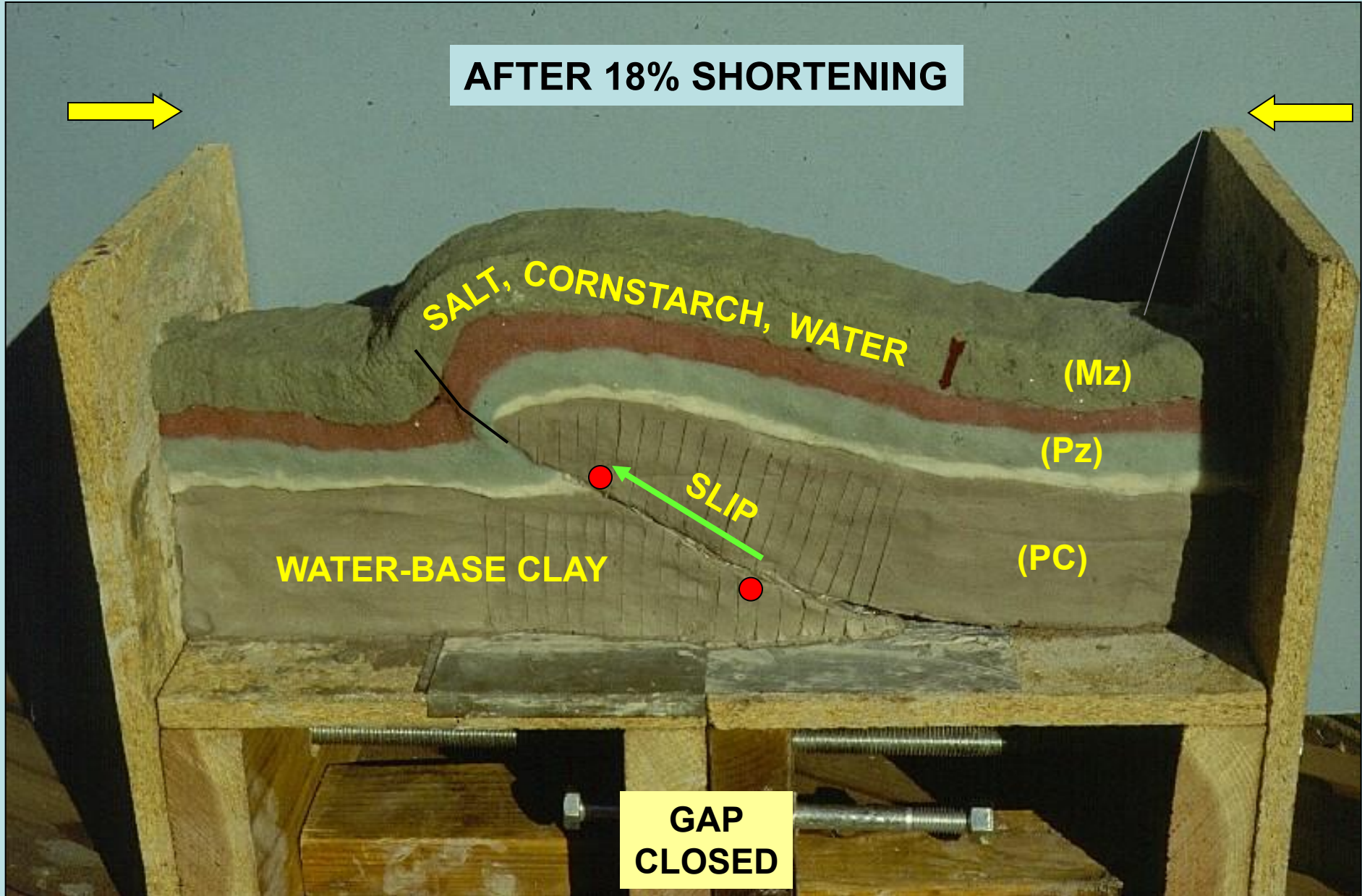
(Pz)

SLIP

WATER-BASE CLAY

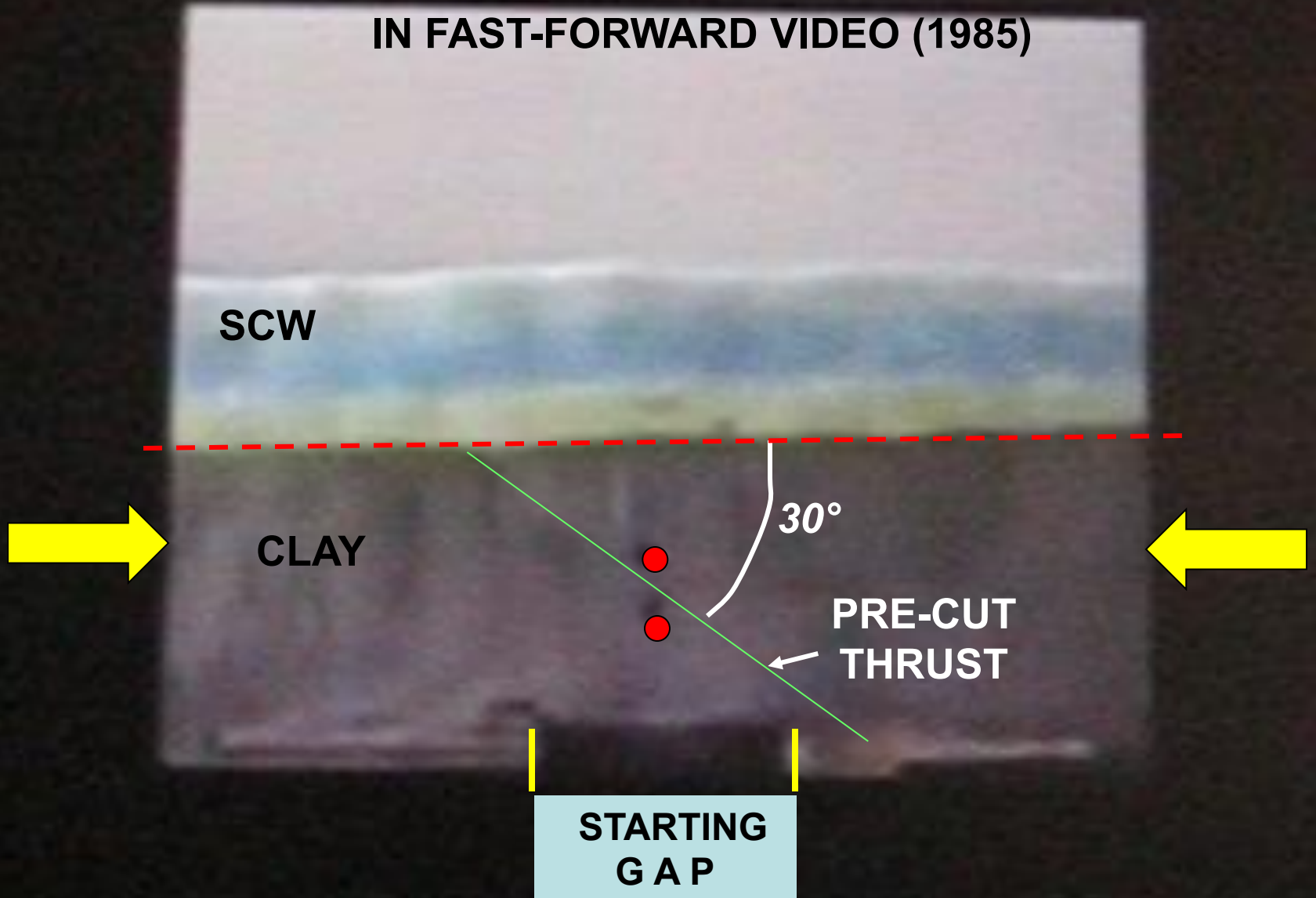
(PC)

GAP
CLOSED



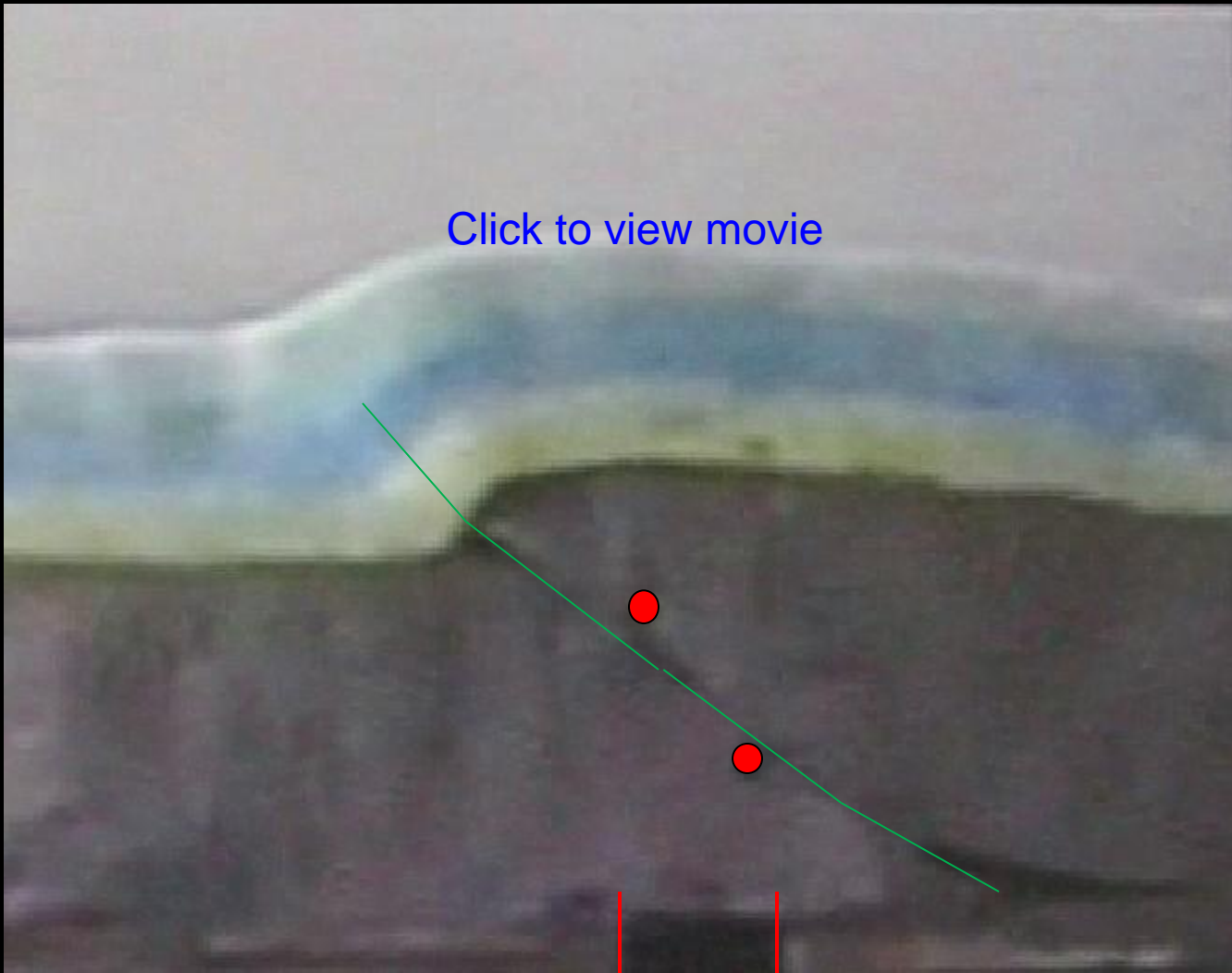


ANALOGUE CLAY-MODEL STUDY OF A BASEMENT-INVOLVE THRUST-GENERATED FOLD (BITGF) IN FAST-FORWARD VIDEO (1985)



CLAY MODEL MOVIE

[Click to view movie](#)

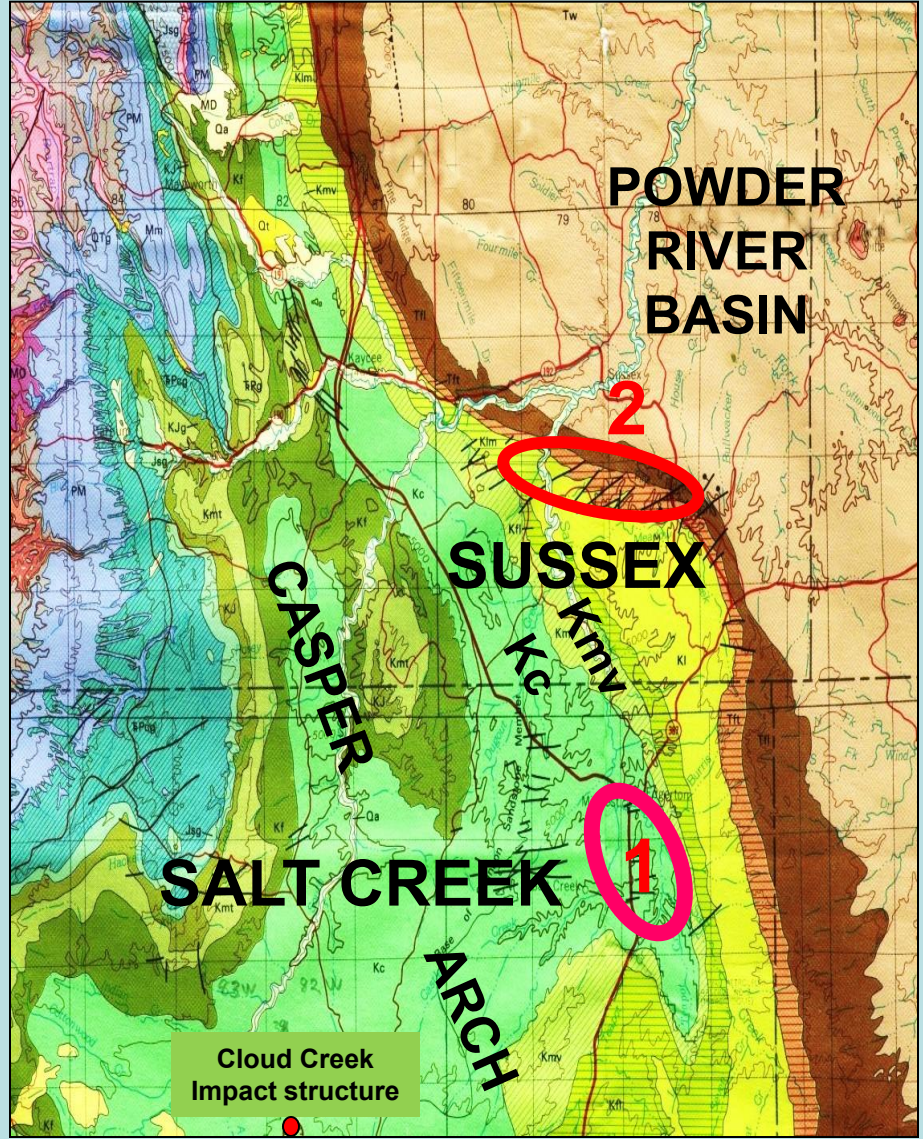




SALT CREEK OIL FIELD, CASPER ARCH, WY

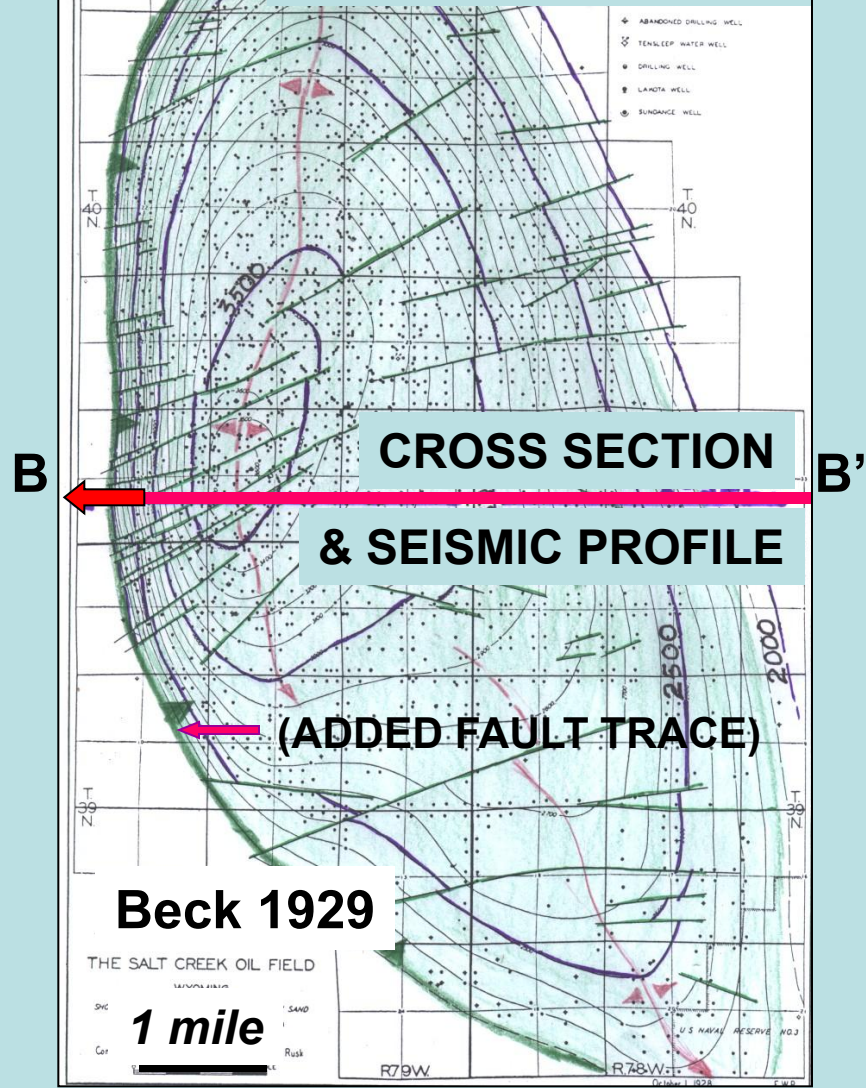
A

FROM GEOLOGIC MAP OF WYOMING



B

2nd WALL CREEK SS
C.I. = 100/500 ft.





TRUE-SCALE CROSS SECTION SALT CREEK OIL FIELD

from Stone, 2005
E

W

B

B'

3000

Ksh

Kwc

S.L.

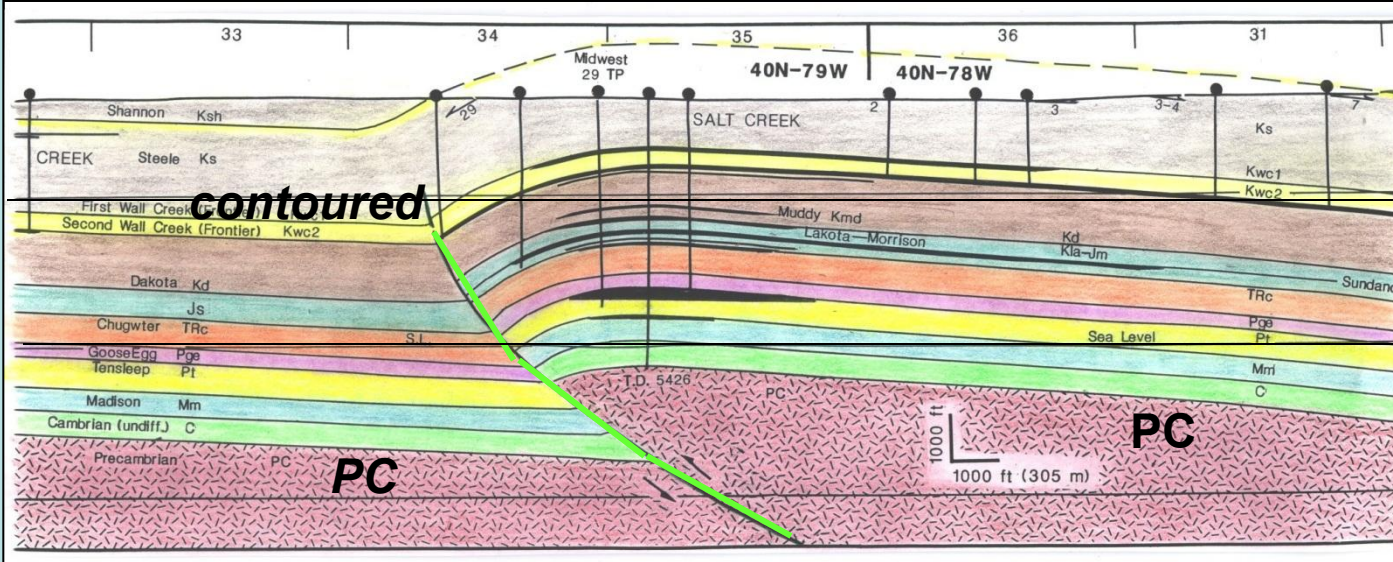
Kd

TRc

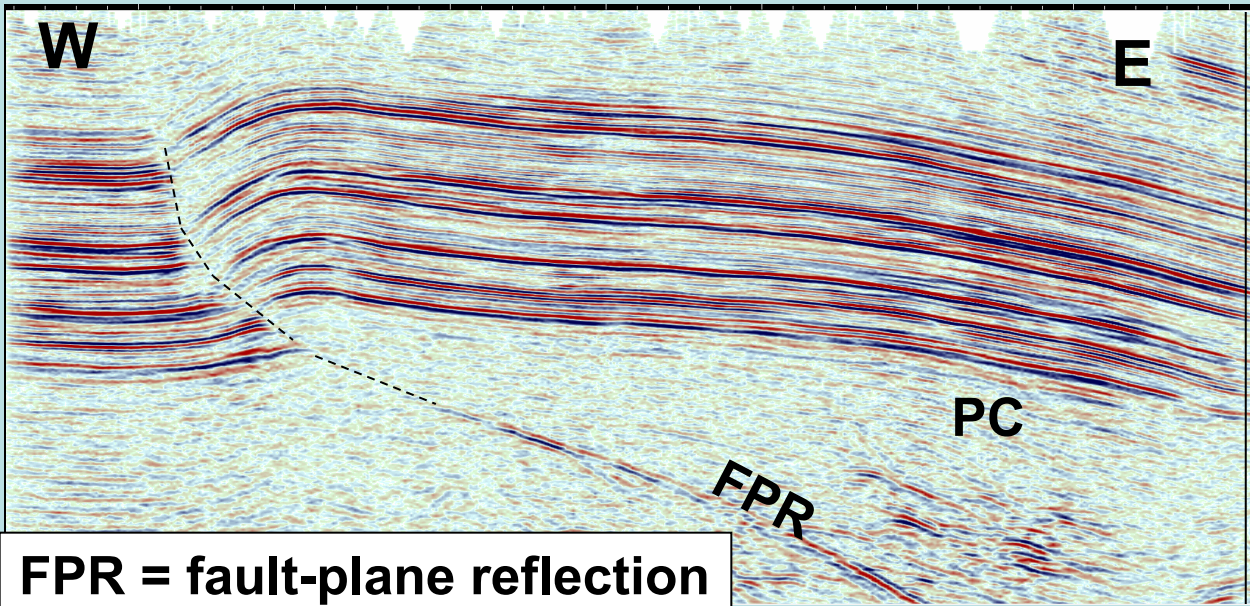
Pt

Mm

-3000



**SEISMIC PROFILE:
TIME-MIGRATED
FROM ©ANADARKO
3D SURVEY
Used by permission
(SAME LOCATION)**



FPR = fault-plane reflection



SALT CREEK

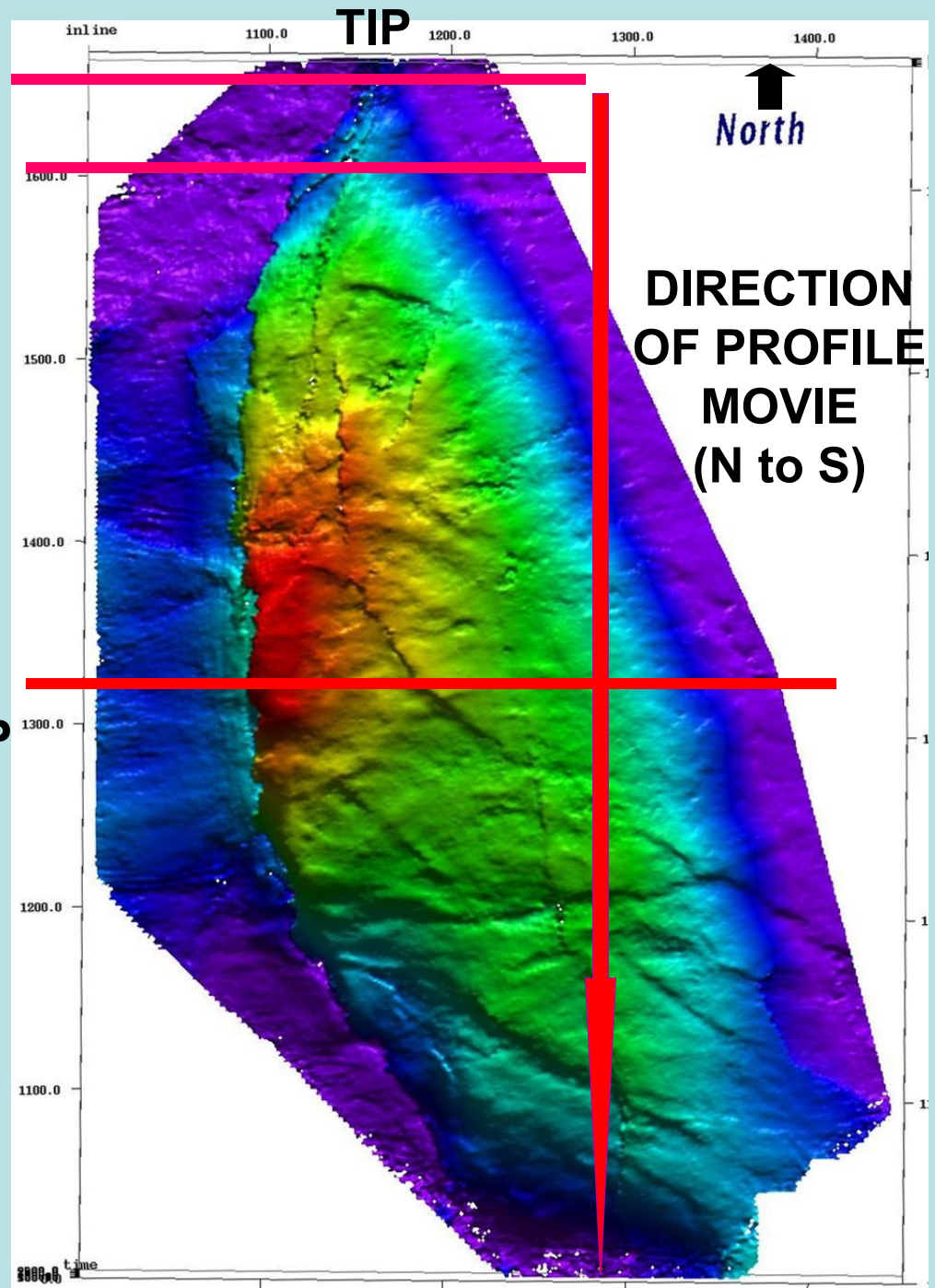
A MATURE
BASEMENT-INVOLVED
THRUST-GENERATED
FOLD

TOP-OF-BASEMENT
STRUCTURE MAP
(from 3D survey)

MAXIMUM
THRUST SLIP

hot colors indicate
structurally highest areas

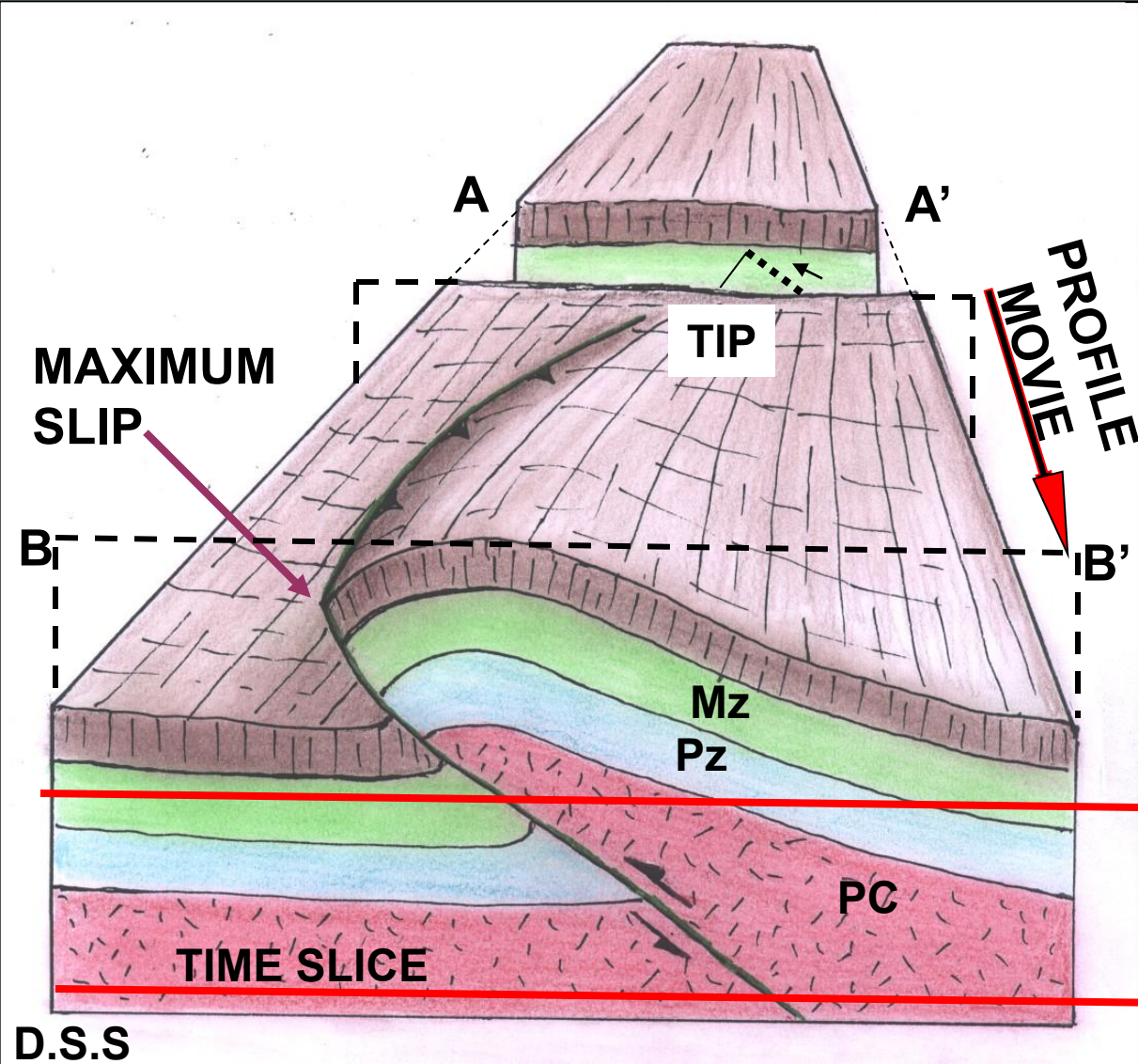
COURTESY OF ©ANADARKO
and Oscar Quezada
Used by Permission





An animation (1st movie) of E-W profiles from A-A' toward B-B' replicates the kinematic development of the Salt Creek BITGF assuming self-same imaging

CONCEPTUAL
3D SKETCH



NO SCALE

D.S.S

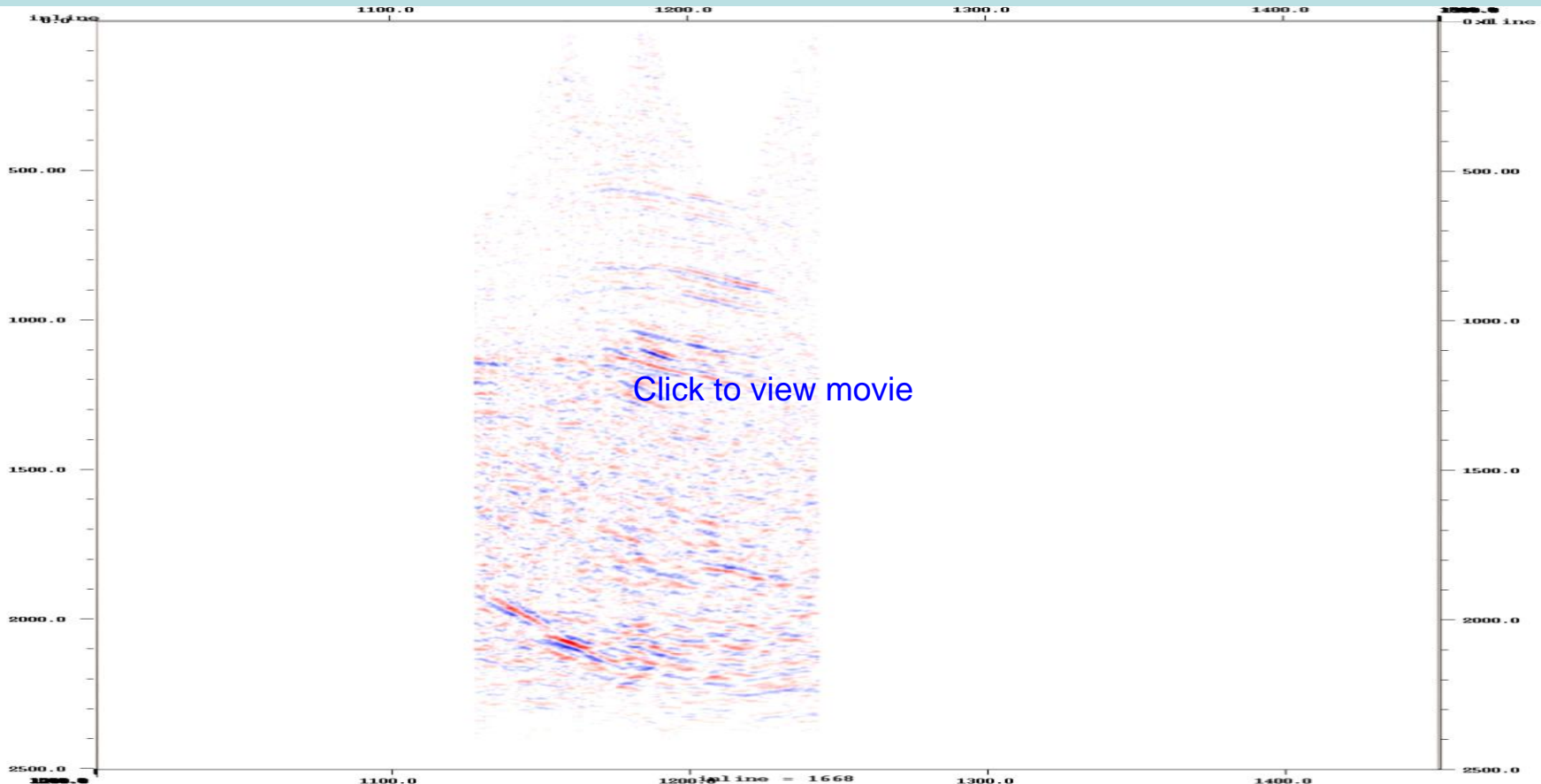


MOVIE OF E-W TIME-MIGRATED SEISMIC PROFILES made from 3D data volume illustrating the kinematic development of a mature basement-involved thrust-generated fold by **self-same imaging** when running from the tip to the center of the structure

W

SCALE ~1:1

E





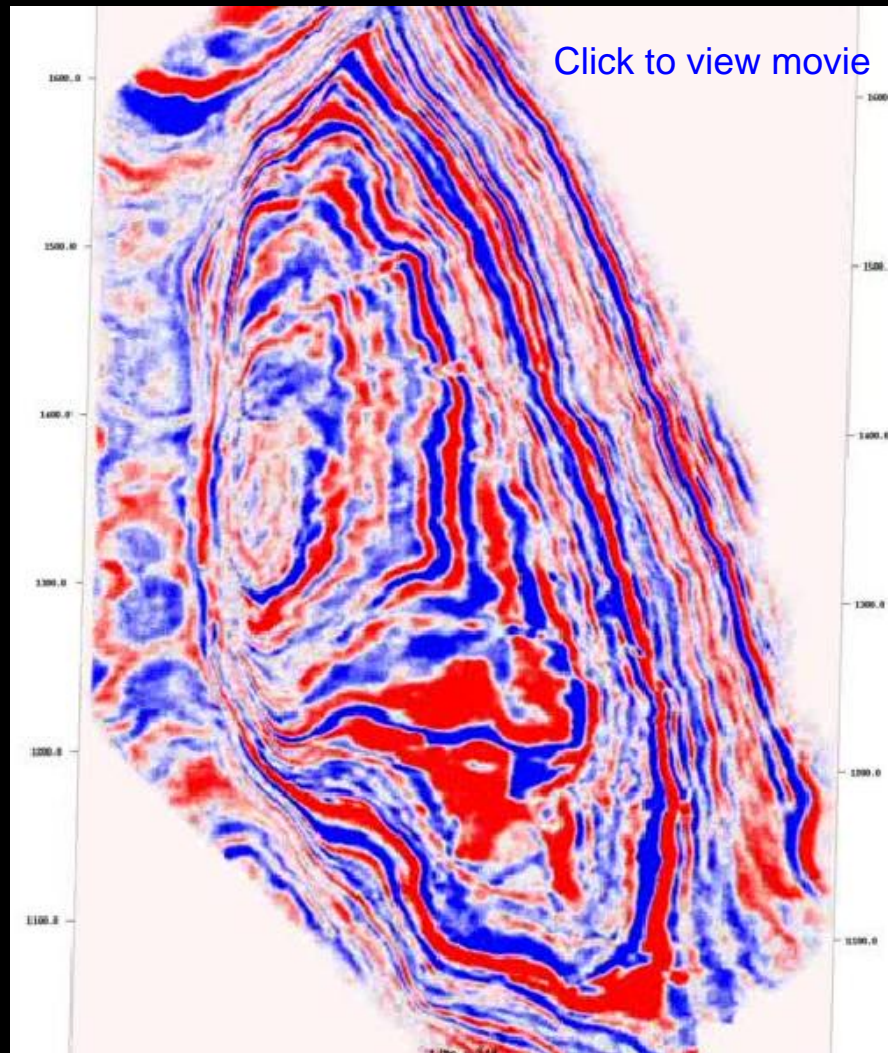
**TIME-SLICE (2nd) MOVIE
FROM 3D SURVEY OF
SALT CREEK OIL FIELD,
MOVING FROM DEEP
IN PRECAMBRIAN
BASEMENT TO THE
SURFACE**

**WATCH FOR THE DEVELOPMENT OF
THE CAUSAL, FOLD-GENERATING
THRUST PLANES**

**(i.e., FAULT-PLANE
REFLECTIONS)**

**AS THEY MIGRATE UPWARD AND WESTERLY
TO THE FORELIMB OF THE
SALT CREEK ANTICLINE**

TIME-SLICE ANIMATION SALT CREEK OIL FIELD





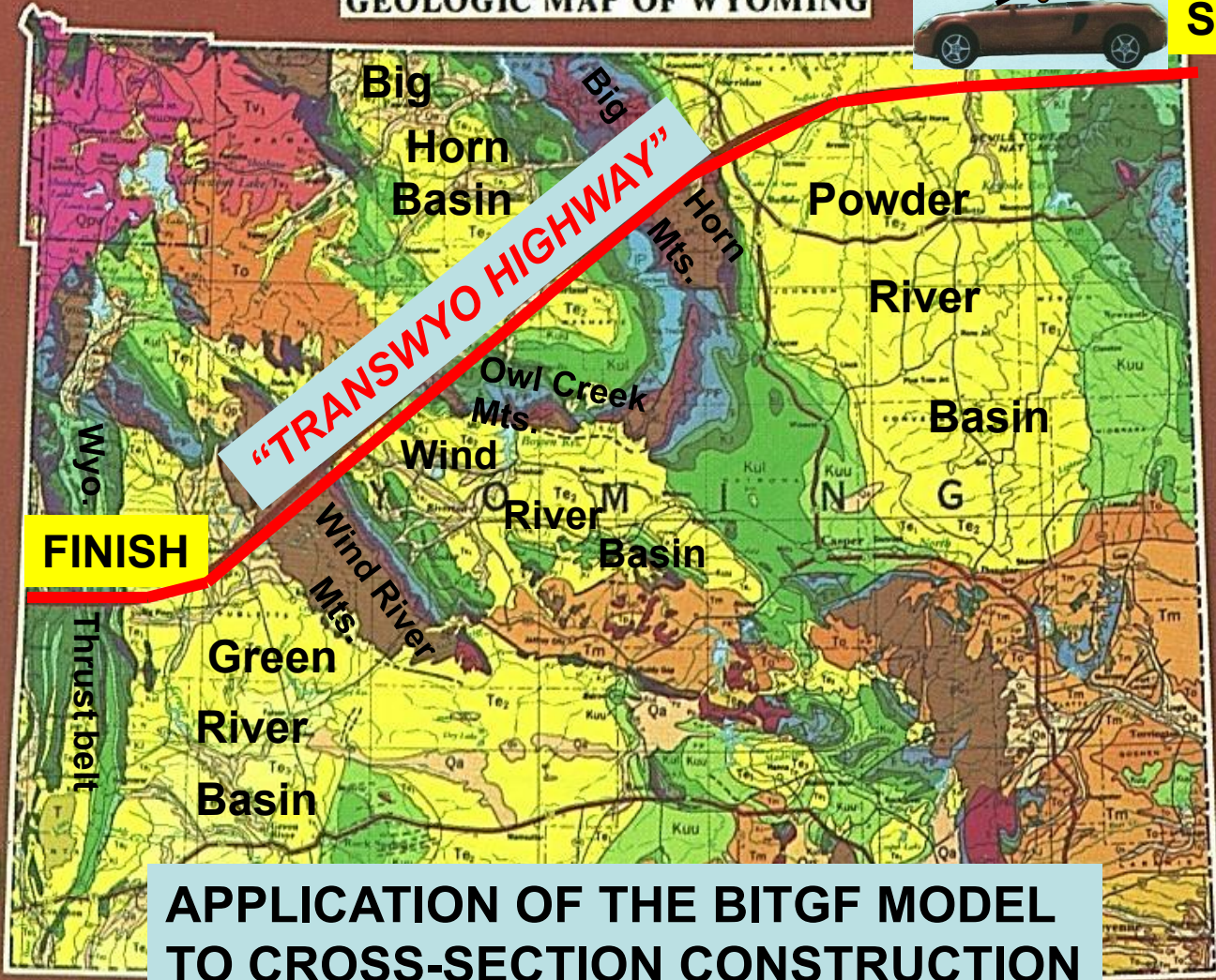
(Well --- Susie heard about the new **Transwyo highway** and decided to go view the BITGFs exposed in the roadside outcrop --- with the top down.)

Paleozoic Mesozoic Tertiary

GEOLOGIC MAP OF WYOMING



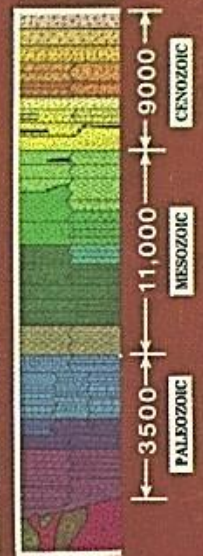
START



Western



Eastern



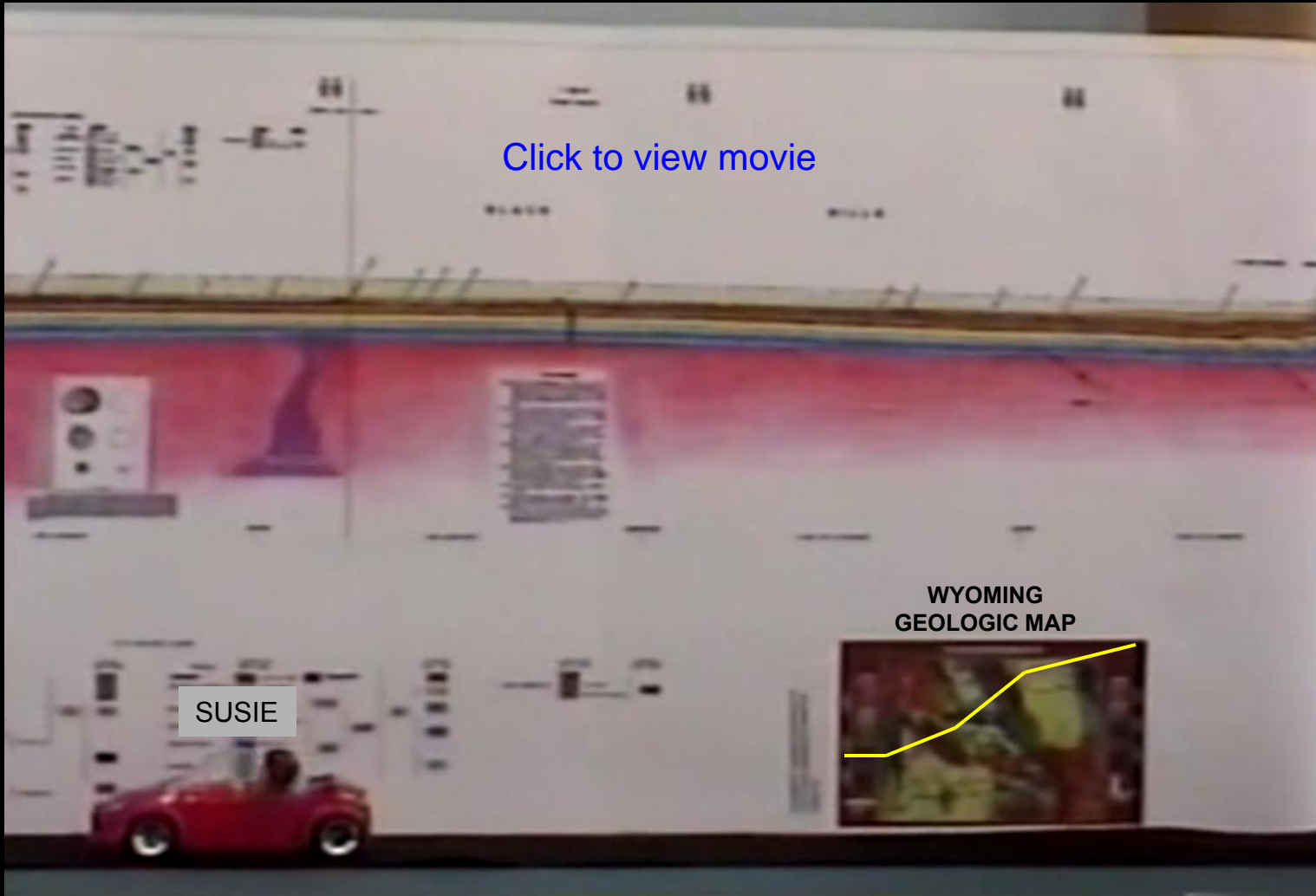
16°E.
Average magnetic declination

APPLICATION OF THE BITGF MODEL TO CROSS-SECTION CONSTRUCTION

[Click to view movie](#)

WYOMING
GEOLOGIC MAP

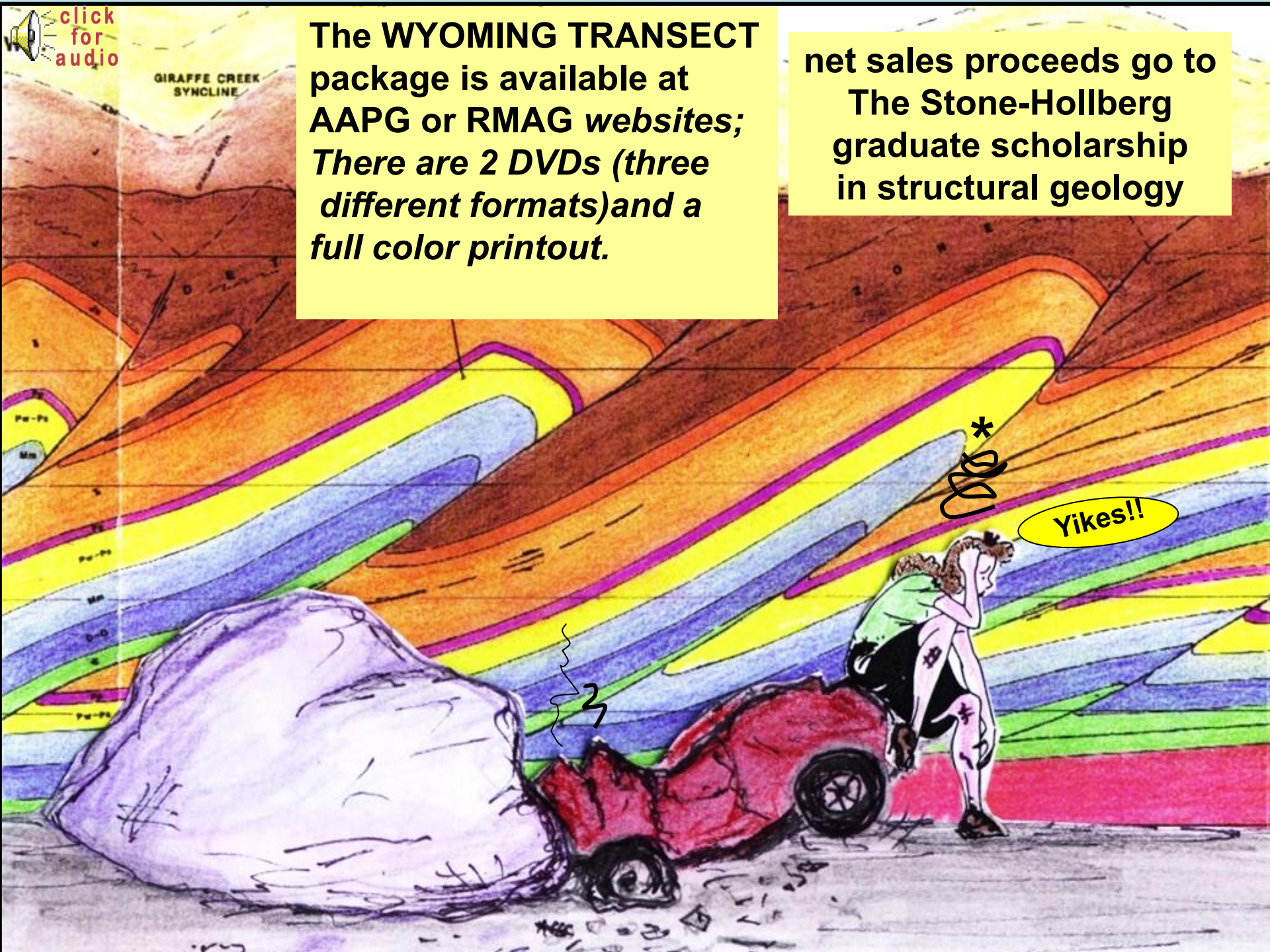
SUSIE



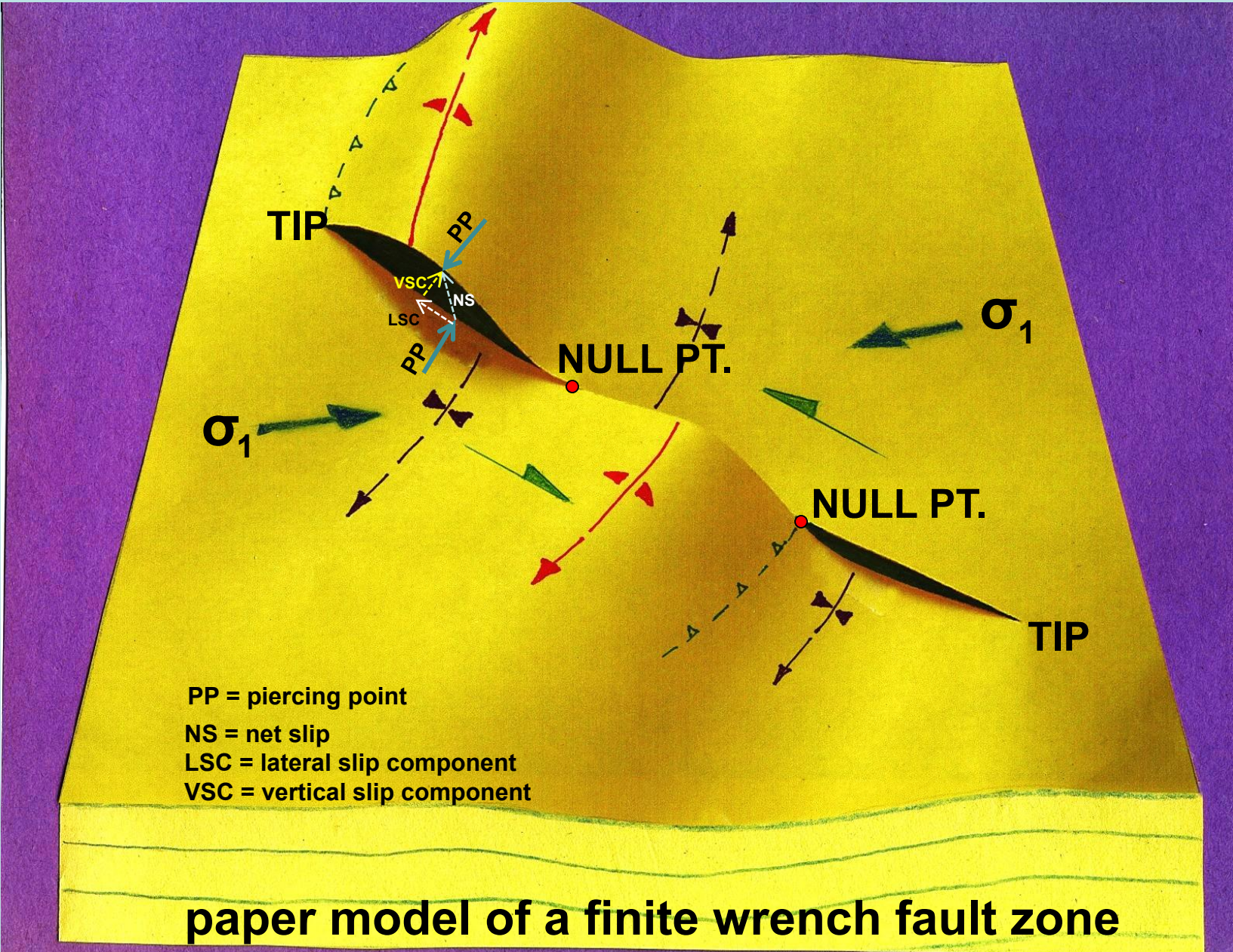


The WYOMING TRANSECT package is available at AAPG or RMAG websites; There are 2 DVDs (three different formats) and a full color printout.

net sales proceeds go to The Stone-Hollberg graduate scholarship in structural geology



click for audio **BASCULATION ALONG A LEFT WRENCH FAULT**

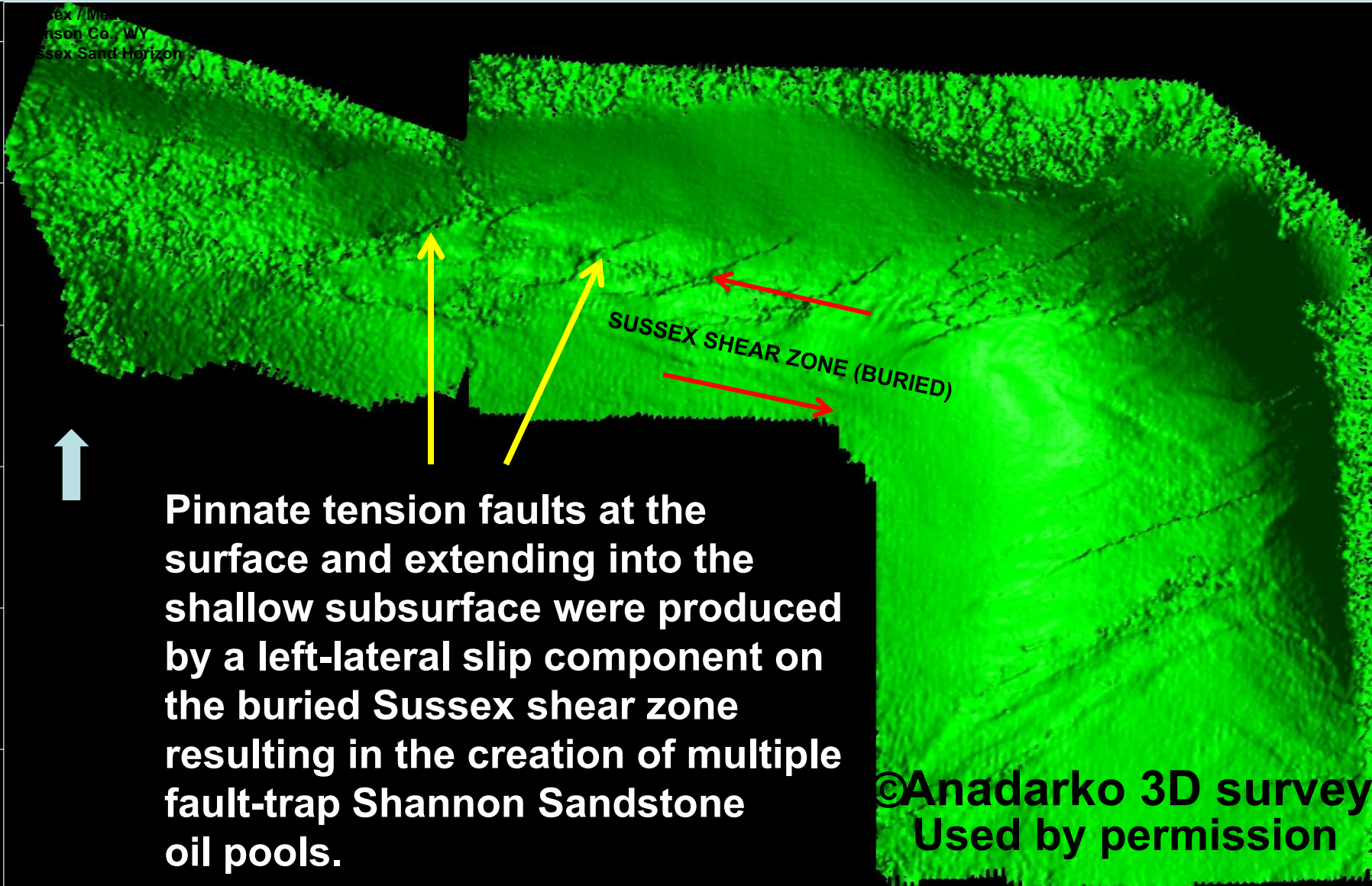


paper model of a finite wrench fault zone



SUSSEX-MEADOW CREEK AREAS

SHANNON SAND HORIZON (shallow)



Sussex / Meadow
Shannon Co., WY
Sussex Sand Horizon

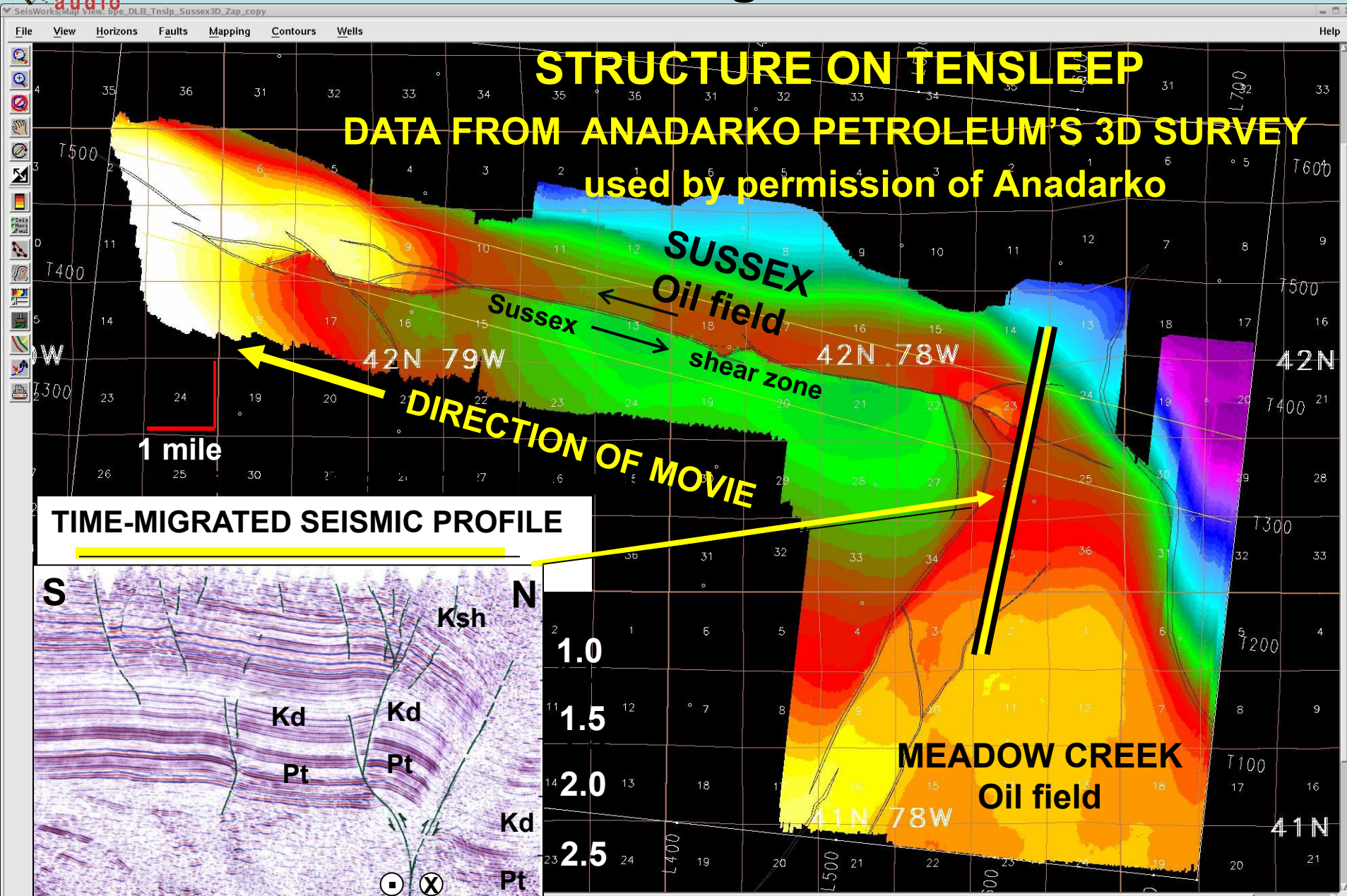
SUSSEX SHEAR ZONE (BURIED)

Pinnate tension faults at the surface and extending into the shallow subsurface were produced by a left-lateral slip component on the buried Sussex shear zone resulting in the creation of multiple fault-trap Shannon Sandstone oil pools.

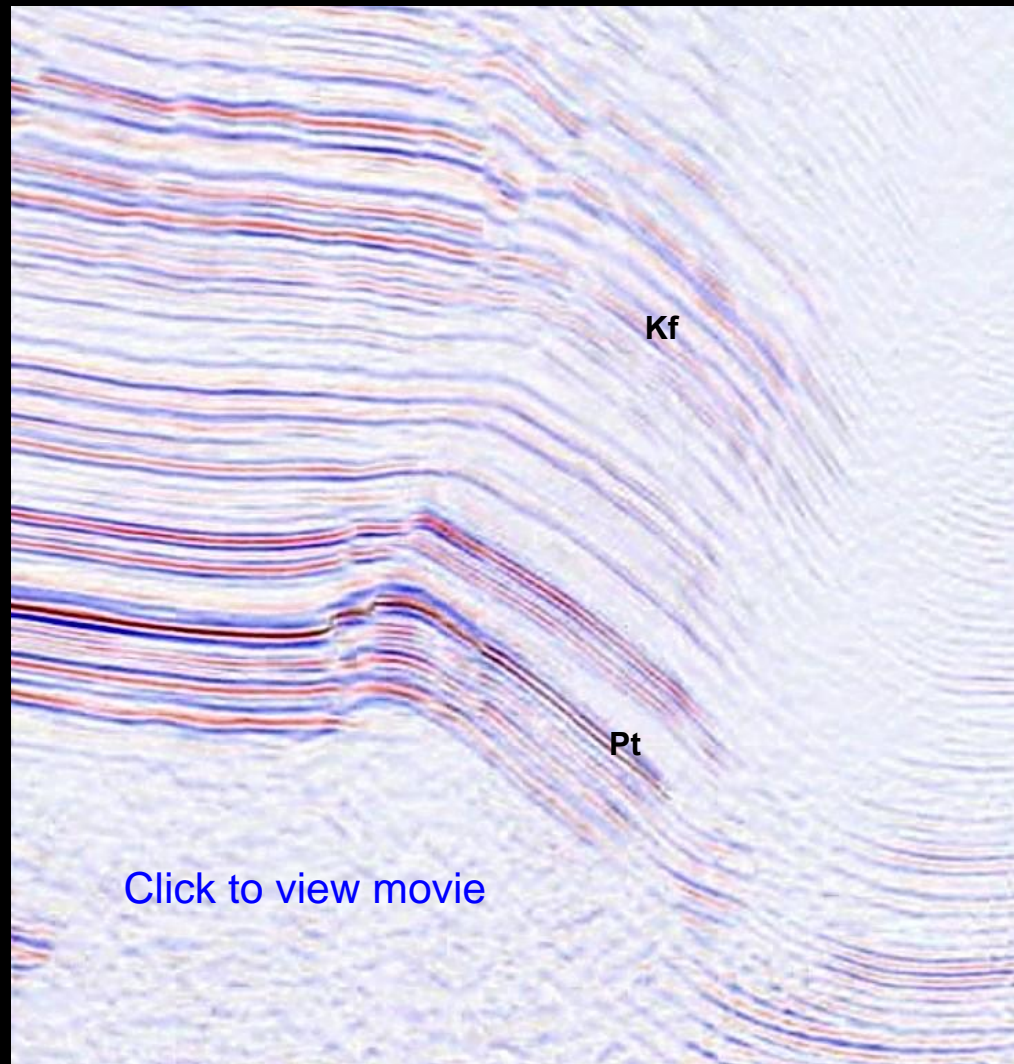
©Anadarko 3D survey
Used by permission



SUSSEX; basculating wrench fault zone



SUSSEX PROFILE ANIMATION



Used by permission of Anadarko, whose permission is required for further use.



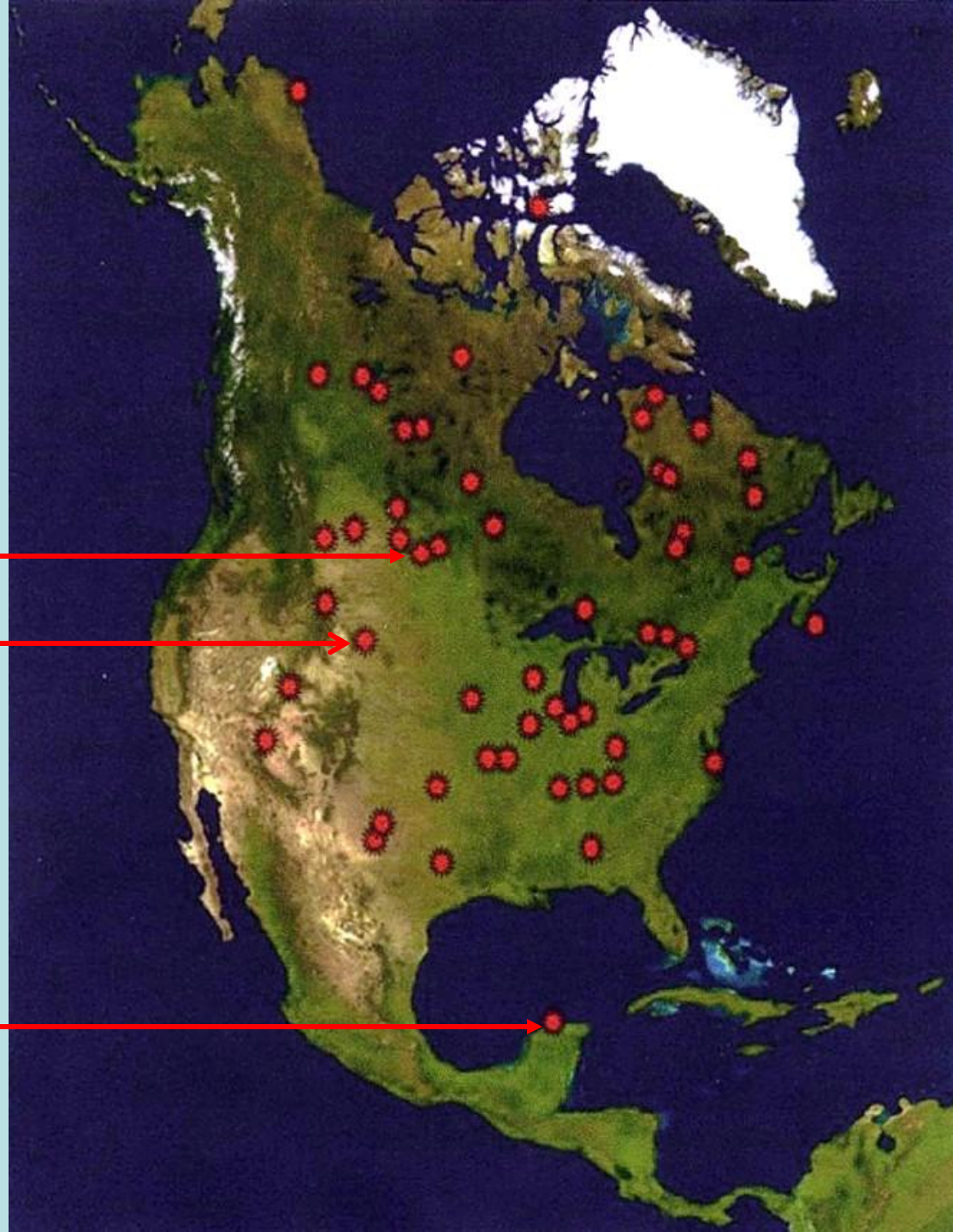
● **CONFIRMED
IMPACT STRUCTURES OF
NORTH AMERICA**

RED WING CREEK

CLOUD CREEK

**Chronostratigraphically
dated as 200 ± 10 Ma**

CHICXULUB





AAPG TECTONIC MAP OF NORTH AMERICA

RED WING CREEK COMPLEX IMPACT STRUCTURE



Crater diameter:
9 km (6 mi)

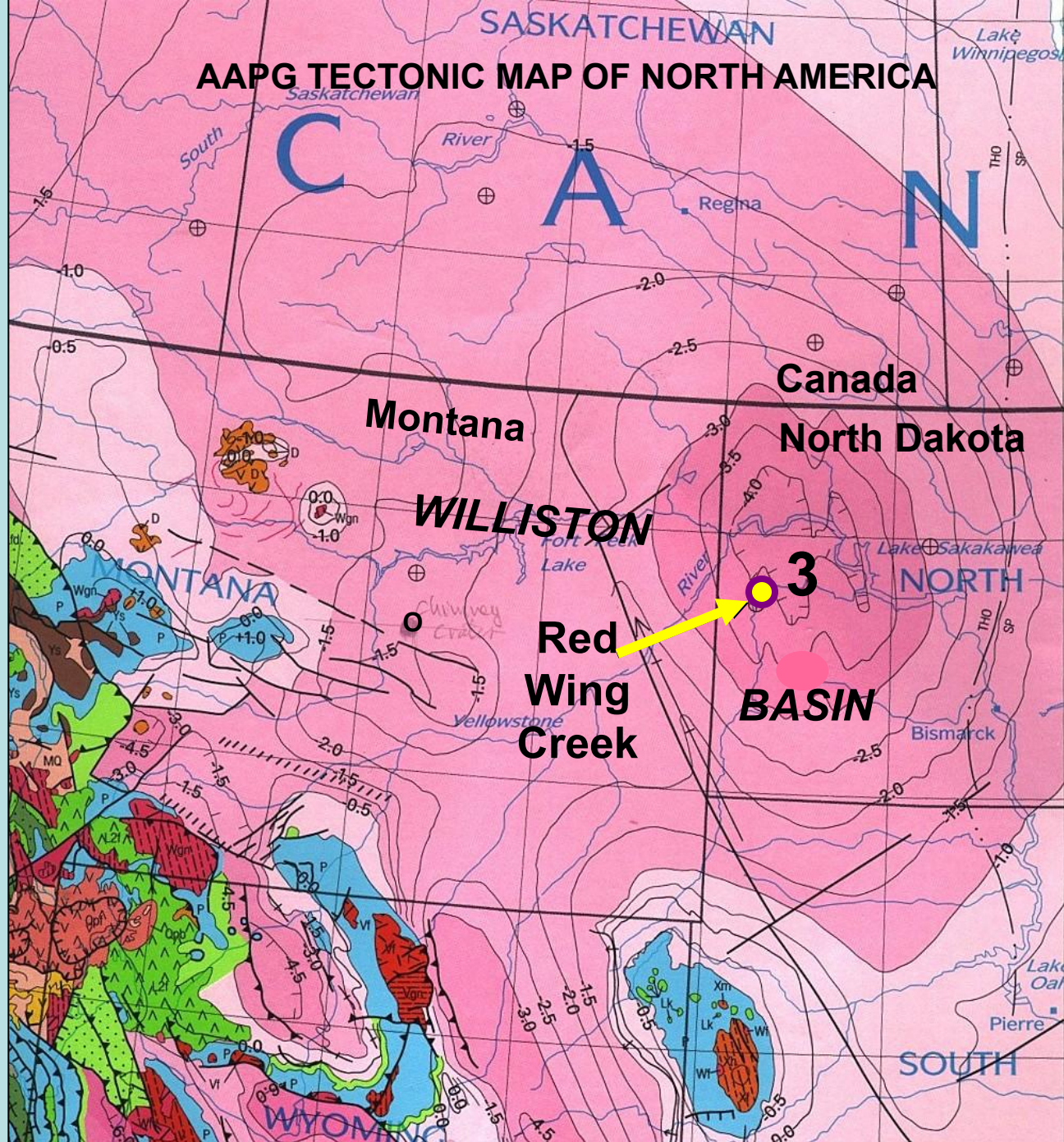
central peak height:
900 m (3000 ft)

Estimates:

Projectile diameter:
450 m (1475 ft)

Projectile velocity:
20 km/s (12.4 mi/s)

Energy (TNT equiv.):
11,000 MT (megatons)



WATER DROP MOVIE
SHOWING IMPACT,
EJECTION STAGE,
CENTRAL REBOUND,
AND RING FORMATION

[Click to view movie](#)

**Analogous to Red Wing Creek
Kinematic development**

click
for
audio

OUTER RIM

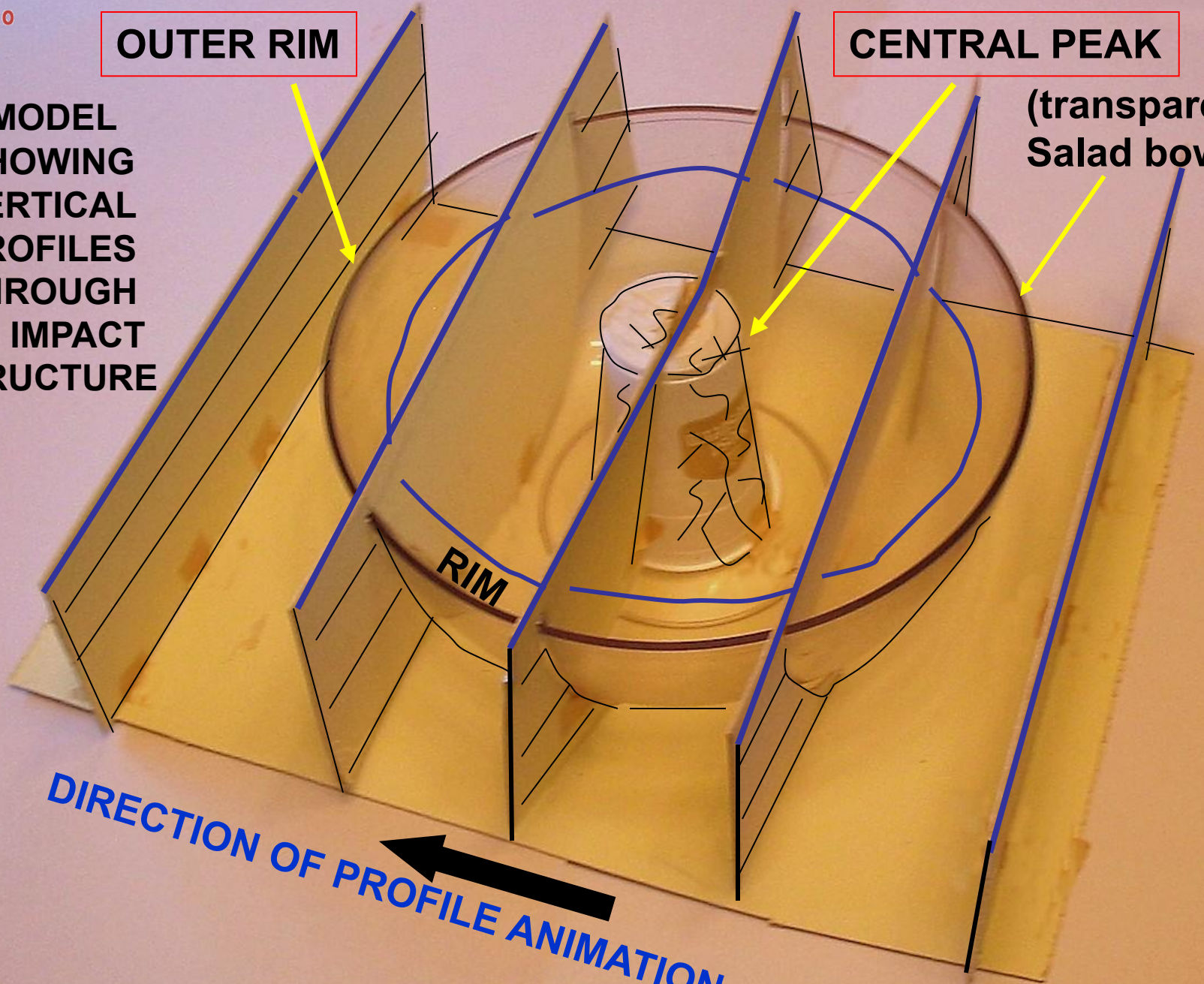
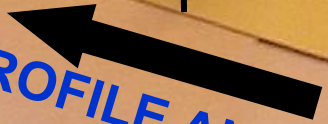
CENTRAL PEAK

**MODEL
SHOWING
VERTICAL
PROFILES
THROUGH
AN IMPACT
STRUCTURE**

(transparent
Salad bowl)

RIM

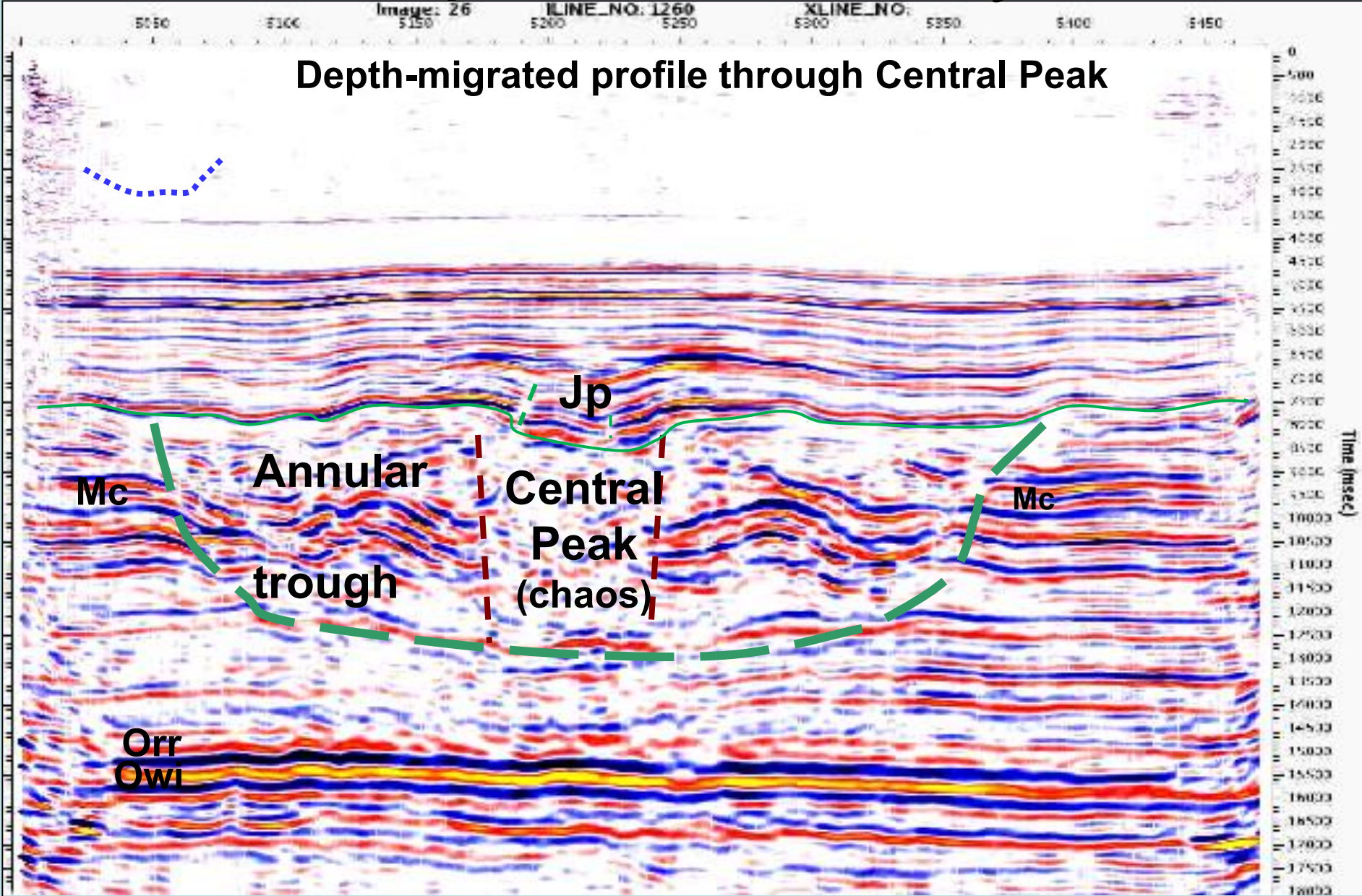
DIRECTION OF PROFILE ANIMATION



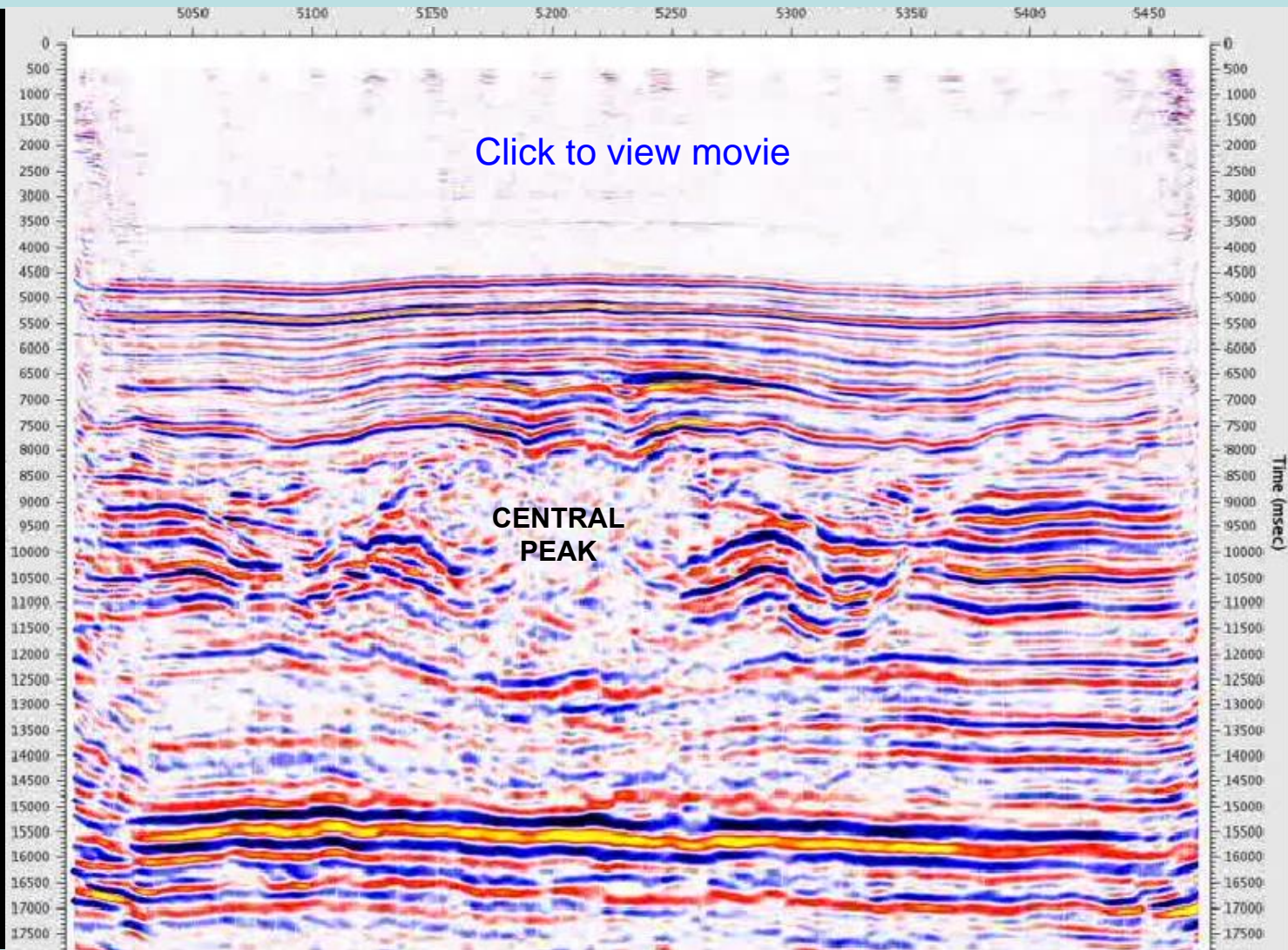


RED WING CREEK IMPACT STRUCTURE

From 3D survey Courtesy of True Oil Co.



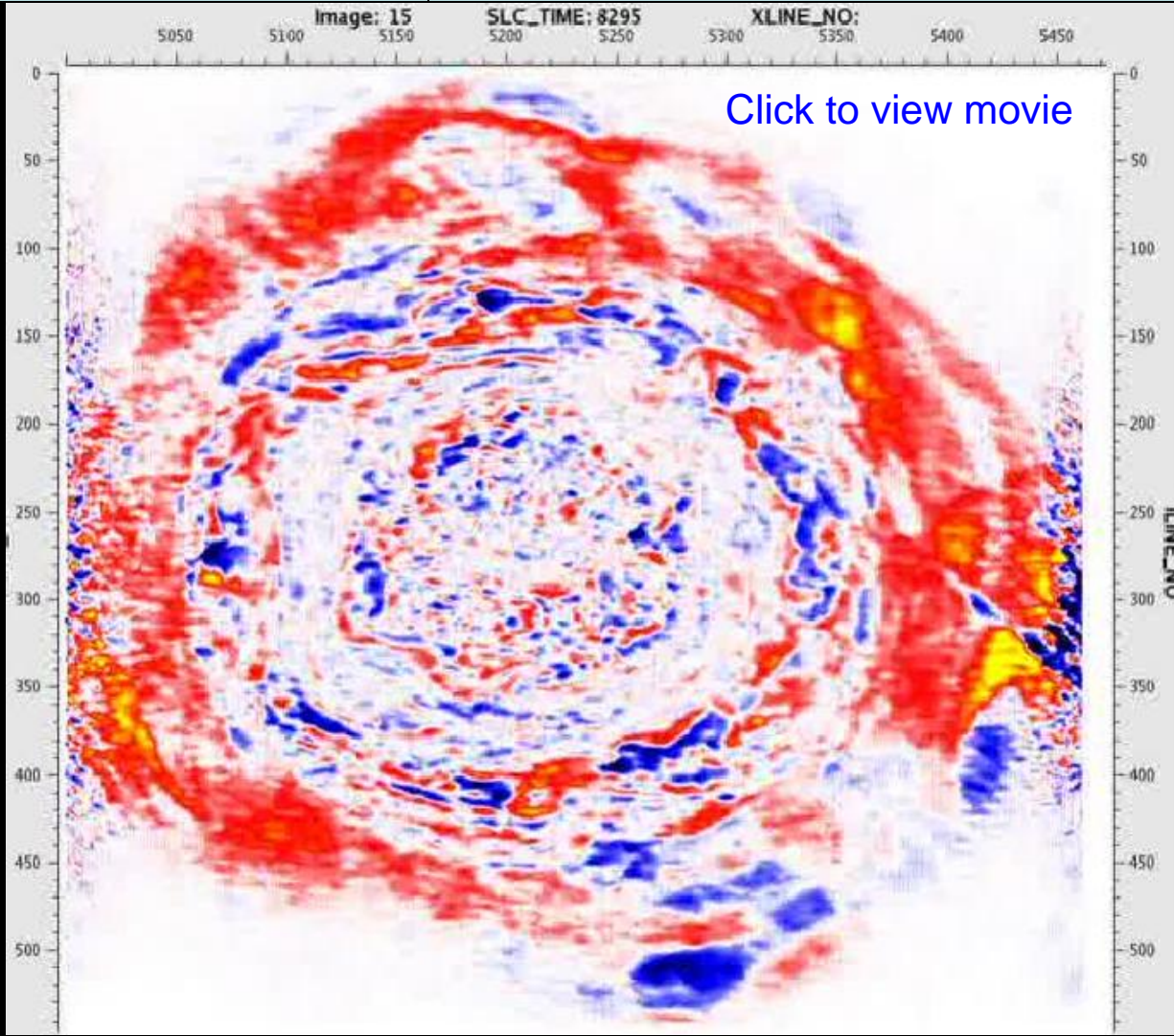
RED WING CREEK PROFILE MOVIE



RED WING CREEK

TIME SLICE MOVIE

DEPTH ↓



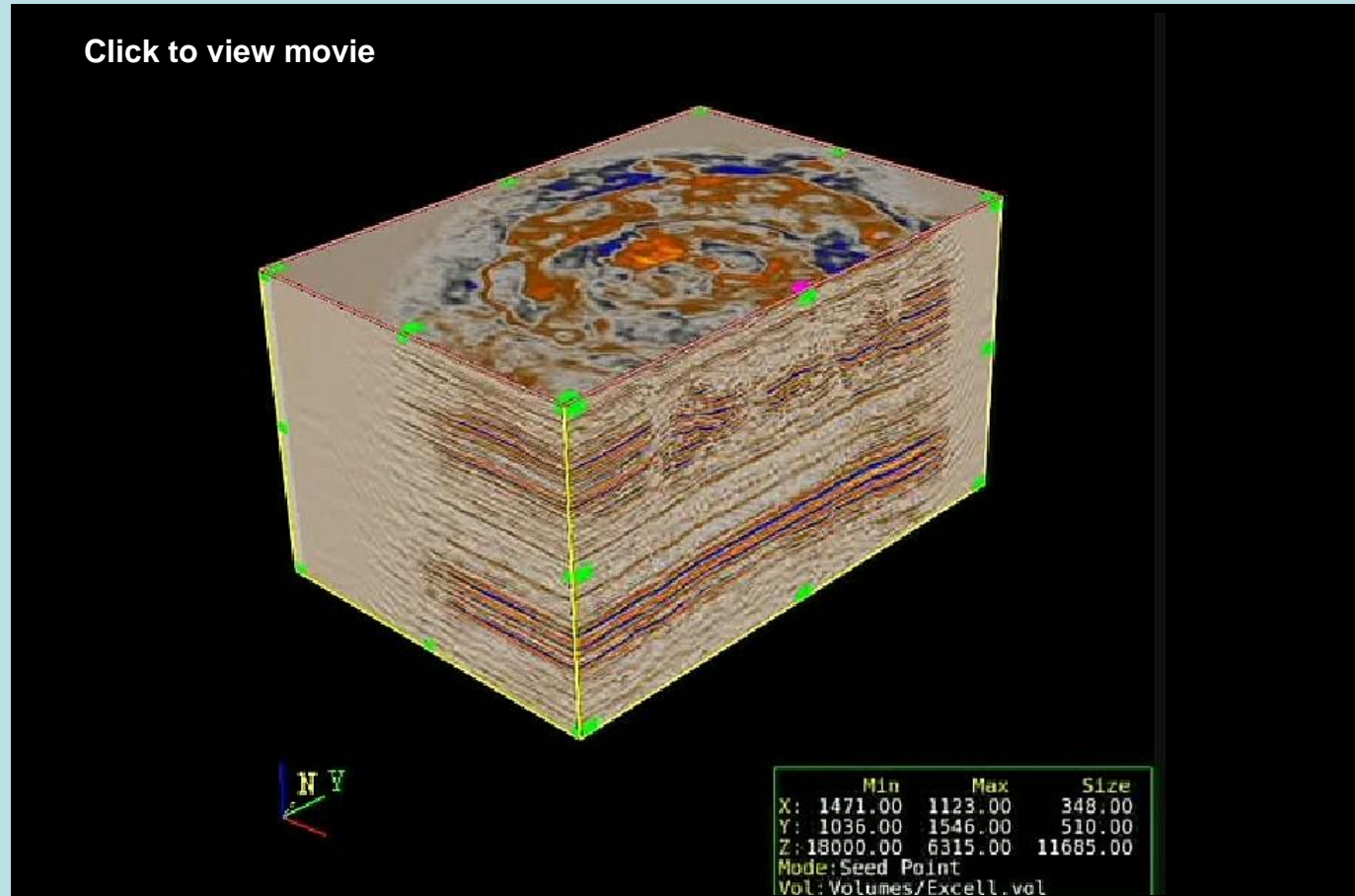
RED WING CREEK IMPACT STRUCTURE

ANIMATION (MOVIE)
FROM 3D SURVEY

DEPTH-MIGRATED
3D DATA VOLUME

COURTESY OF
TRUE OIL COMPANY
(Roger Barton)

animation by
Larry Fink
at Landmark
(Halliburton)



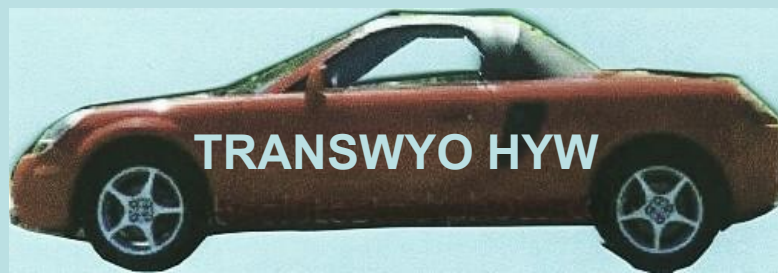
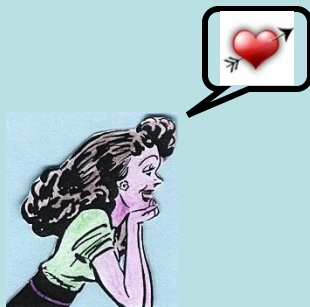


CONCLUSIONS

- Seismic-profile and time-slice animations made from 3D data volumes provide a unique source of visual data for kinematic analysis of subsurface geologic structures based on the concept of **self-same imaging**.
- The 3D movies of the three classes of foreland structures – ***basement-Involved thrust-generated folds, basculating wrench-faults, and terrestrial impact structures*** – should leave you with a clear visual image of the kinematic development of these characteristic geologic structures.

AND ---

- Susie loves her new convertible (paid for by insurance)!



ACKNOWLEDGEMENTS

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Ira Pasternack (Comet Ridge Resources, LLC.)

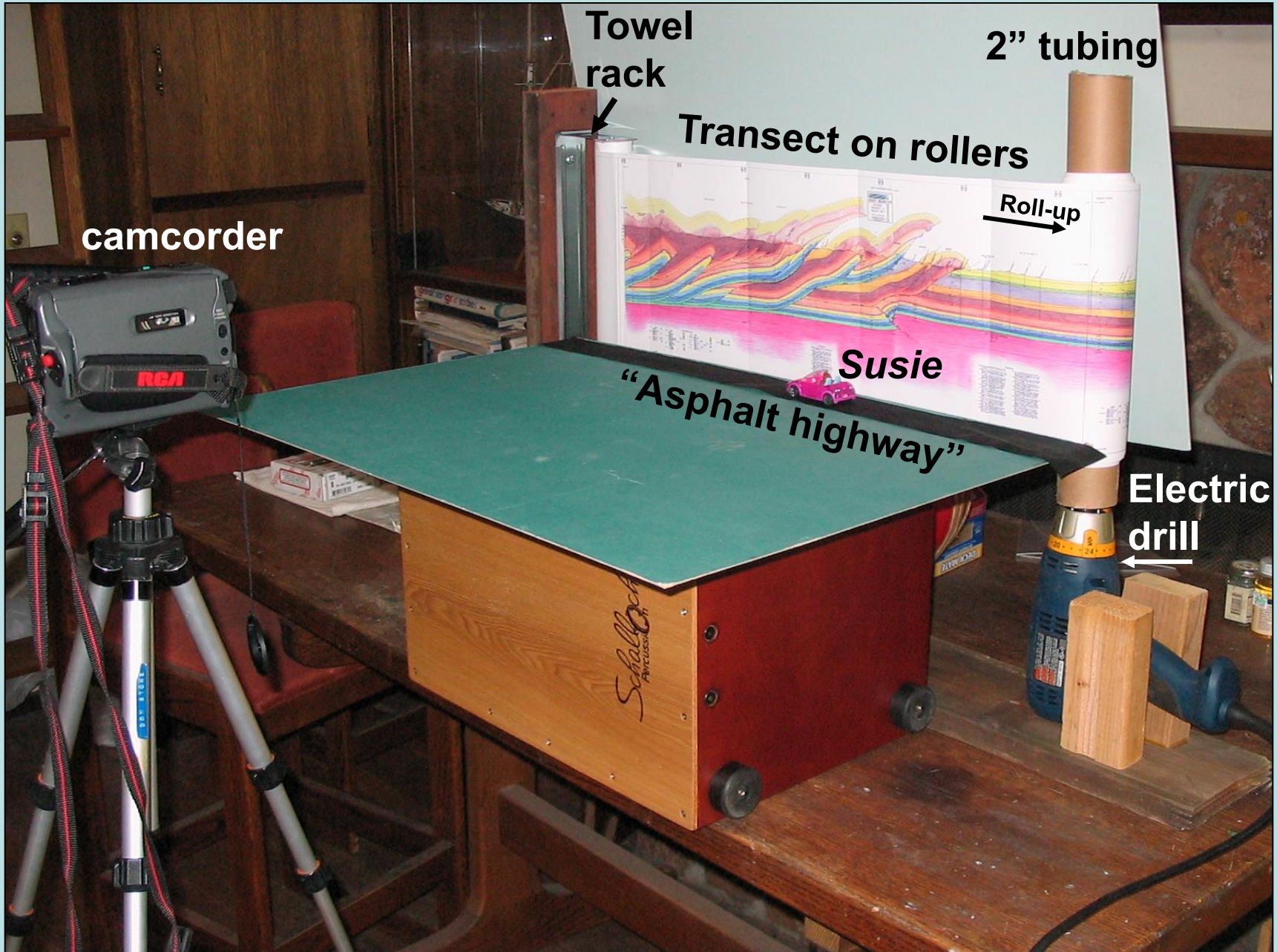
Pencho Dimitroff (“camcorder operator”)

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SETUP FOR MOVIE OF SUSIE'S WYOMING TRANSECT ADVENTURE



camcorder

Towel rack

2" tubing

Transect on rollers

Roll-up

Susie

"Asphalt highway"

Electric drill

Schalbach Percussion Co.